Astronomy is the study of the heavens, the realm extending from beyond the Earth's atmosphere to the most distant reaches of the Universe. Within this vast space we discover an amazing diversity of planets, stars, and galaxies. That creatures as tiny as ourselves cannot only contemplate but also understand such diversity and immensity is amazing. But even more amazing are the objects themselves: planets with dead volcanos whose summits dwarf Mount Everest, stars a hundred times the size of the Sun, and galaxies—slowly whirling clouds of stars—so vast that they make the Earth seem a grain of sand in comparison. All this is the cosmic landscape in which we live, a landscape we will briefly explore now to familiarize ourselves with its features and to gain an appreciation of its vast scale.

P.1 THE EARTH, OUR HOME

We begin with the Earth, our home **planet** (fig. P.1). This spinning sphere of rock circling the Sun is huge by human standards, but it is one of the smallest bodies in the cosmic landscape. Nevertheless, it is an appropriate place to start because, as the base from which we view the Universe, it influences what we can see. We cannot travel from object to object in our quest to understand the Universe. Instead, we are like children who know their neighborhood well but for whom the larger world is still a mystery, known only from books and television at second hand.

But just as children use knowledge of their neighborhood to build their image of the world, so astronomers use their knowledge of Earth as a guide to more exotic worlds.

FIGURE P.1
The planet Earth, our home, with blue oceans, white clouds, and multihued continents.
(Courtesy of NASA.)

For example, volcanos that spew molten lava and geysers that shoot hot water into the air suggest that the center of the planet we live on seethes with heat. This heat stirs molten rock within the Earth, creating slow but powerful currents that shift our planet's crust, building mountains, heaving up volcanos, and generating a magnetic field. Looking outward to our planetary neighbors, we find landscapes on Venus and Mars that bear evidence of many of the same processes that sculpt our planet and create its diversity. Likewise, when we look at the atmospheres of other planets, we see many of the same features that occur in our atmosphere. For example, winds in the thin envelope of gas that shelters us swirl around our planet much as similar winds sweep the alien landscapes of Venus and Mars.

FIGURE P.2
The Moon, as we see it with unaided eyes. (Courtesy of Stephen E. Strom.)

P.2 THE MOON

The Moon is our nearest neighbor in space, a **satellite** that orbits the Earth some quarter million miles (384,000 km) away. Held in tow by the Earth's gravity, the Moon is much smaller than Earth (only about one-quarter our planet's diameter).

With the naked eye, and certainly with a pair of binoculars, we can clearly see that its surface is totally unlike Earth's. Instead of white whirling clouds, green-covered hills, and blue oceans, we see an airless, pitted ball of rock that shows us the same face night after night (fig. P.2).

Why are the Earth and Moon so different? Their different surfaces arise in large part from their great difference in mass. The Moon's mass is only about 1/80 the Earth's, and its smaller bulk was therefore less able to retain heat. Without that strong internal heat, no crustal motions—so important in shaping Earth—have altered the Moon's surface. In fact, the Moon has changed so little over the past 3 billion years that its surface may hold important clues to what planets may have been like billions of years ago. In addition to this scientific importance, the Moon has symbolic significance for us—it marks the present limit of direct human exploration of space.

P.3 THE PLANETS

Beyond the Moon, circling the Sun as the Earth does, are eight other planets, sister bodies of Earth. In order of their average distance from the Sun and working out, the nine planets are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto. These worlds have dramatically different sizes and landscapes. For example:

- Craters scar the airless surface of Mercury.
- Dense clouds of sulfuric acid droplets completely shroud Venus.
- White clouds, blue oceans, green jungles, and red deserts tint Earth.
- Huge canyons and deserts spread across the ruddy face of Mars.
- Immense atmospheric storms with lightning sweep across Jupiter.
- Trillions of icy fragments orbit Saturn, forming its bright rings.
- Dark rings girdle Uranus, its spin tipped by some cosmic catastrophe.
- Choking methane clouds whirl in the deep blue atmosphere of Neptune.
- Perpetual ice glazes dim Pluto.

To the unaided eye, the other planets are mere points of light whose positions shift slowly from night to night. But by observing them, first with Earth-based telescopes, then ultimately by remotely piloted spacecraft, we have learned that they are truly other worlds. Figure P.3 shows pictures of these nine distinctive bodies and reveals something of their relative size and appearance. Some are far smaller and others vastly larger than Earth, but all are dwarfed by the Sun, whose immense gravity holds them in orbit.

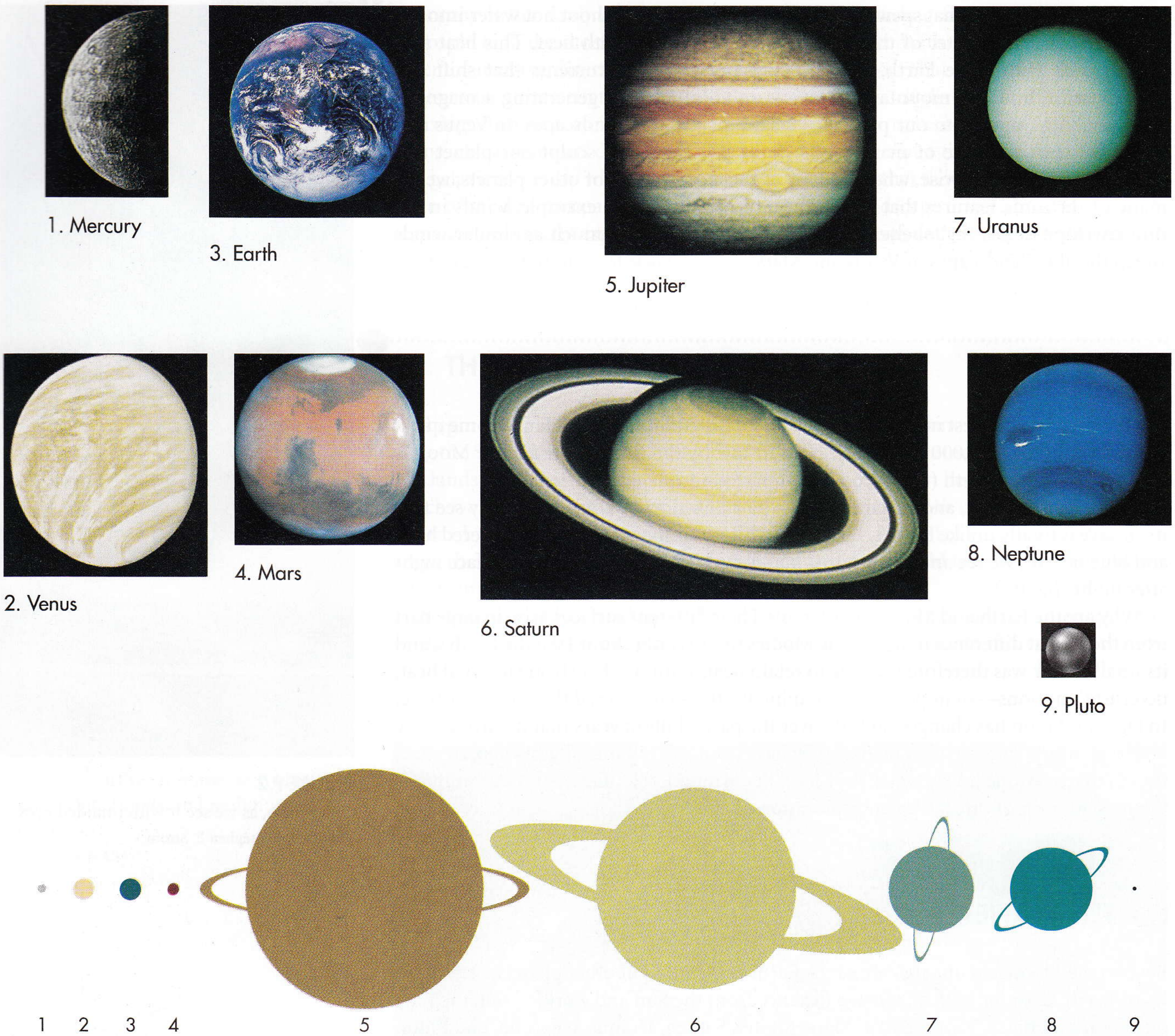


FIGURE P.3
Portraits of the nine planets along with silhouettes showing their correct relative size. All except Pluto's picture were taken by spacecraft.
(Pictures of planets courtesy of NASA/JPL.)

P.4 THE SUN

The Sun is a **star,** a huge ball of gas over 100 times the diameter of the Earth and over 300,000 times more massive: if the Sun were a volleyball, the Earth would be about the size of a pinhead, and Jupiter roughly the size of a nickel (fig. P.4). The Sun, of course, differs from the planets in more than just size: it generates energy in its core by nuclear reactions that convert hydrogen into helium. From the core, the energy flows to the surface, and from there it pours into space to illuminate and warm the planets.

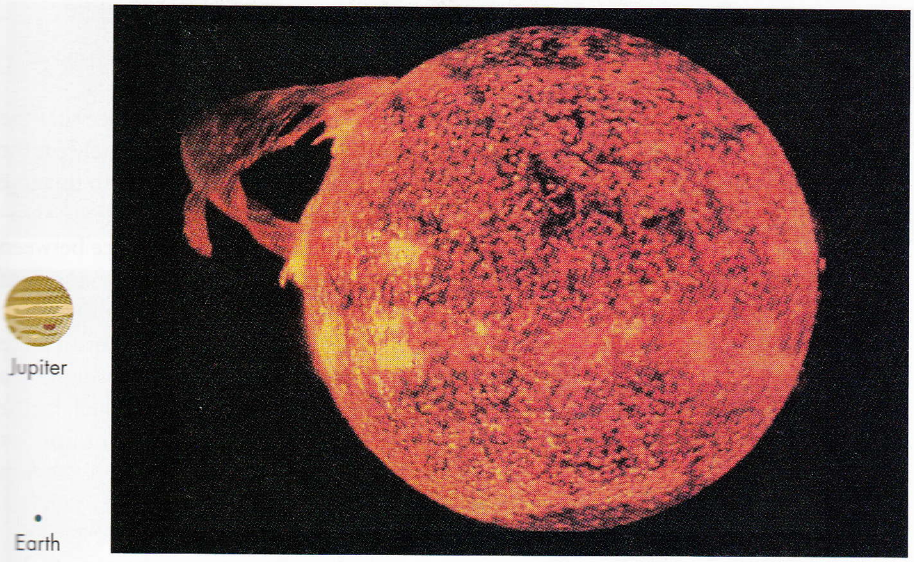


FIGURE P.4
The Sun as viewed through a filter that allows its hot outer gases to be seen. The Earth and Jupiter are shown to scale beside it for comparison.
(Courtesy of Naval Research Laboratory.)

P.5 THE SOLAR SYSTEM

The Sun and its nine planets form the **Solar System.** But smaller bodies—satellites (moons) orbiting the planets, and asteroids and comets orbiting the Sun—also populate the Solar System (fig. P.5).

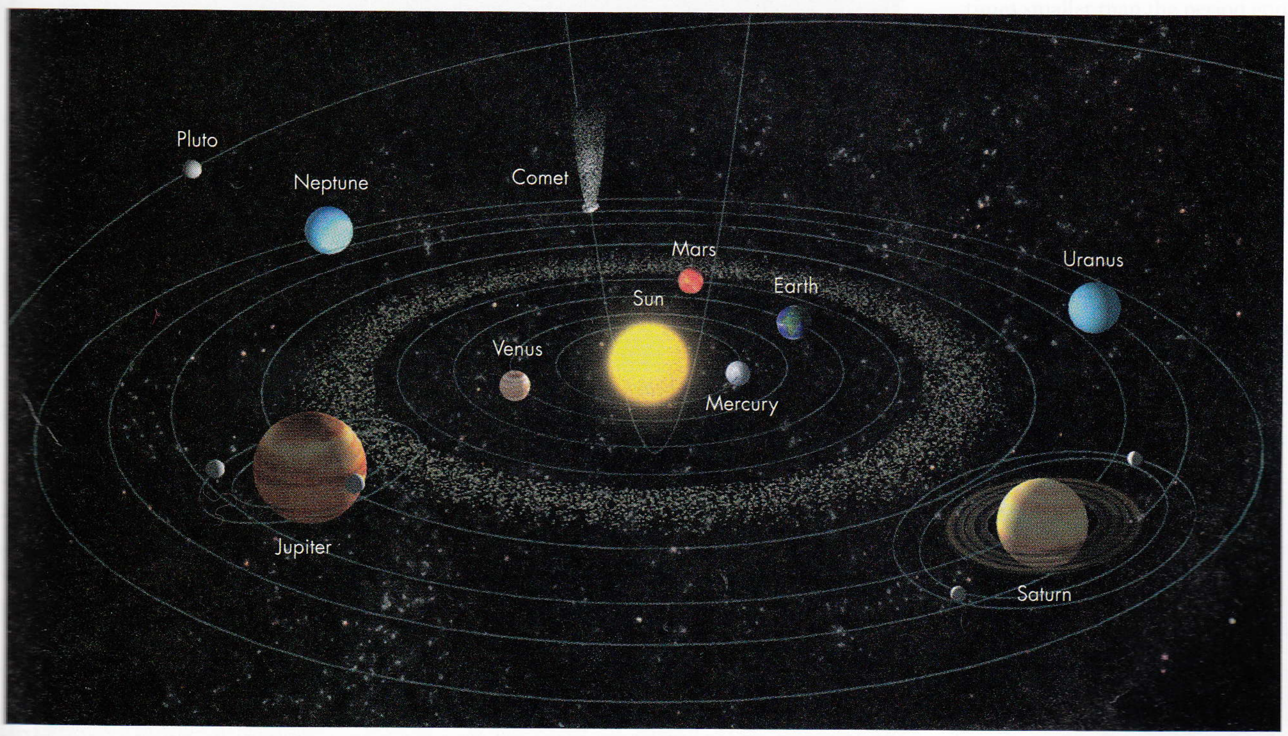


FIGURE P.5
An artist's view of the Solar System showing the Earth and its eight sister planets circling the Sun. Note the asteroids between Mars and Jupiter and the comet moving along its elongated orbit. (In this diagram and many others throughout the book, distances and sizes of astronomical bodies are exaggerated for clarity.)

P.6 A SENSE OF SCALE

If the paths that the planets follow around the Sun were visible, we would see that the Solar System is like a huge set of nested elliptical rings, centered approximately on the Sun and extending about 4 billion miles outward to Pluto's orbit. It is hard to imagine such immense distances measured in miles. In fact, it is as foolish to use miles to measure the size of the Solar System as it is to use inches to measure the distance between New York and Tokyo. Whenever possible, we try to use units appropriate to the scale of what we seek to measure. For example, in earlier times people used units that were quite literally at hand, such as finger widths or the spread of a hand to measure a piece of cloth and paces to measure the size of a field. In the same tradition, although on a different scale, astronomers use distance scales related to familiar objects, such as the Earth. As we shall see in later chapters, the Earth's radius makes a convenient unit for measuring the size of the other planets. Likewise, the Earth's distance from the Sun makes a good unit for measuring the scale of the Solar System.

P.7 THE ASTRONOMICAL UNIT

The **astronomical unit,** abbreviated as AU, is defined by the distance from the Earth to the Sun.* This translates into about 93 million miles (150 million kilometers). If we use the AU to measure the scale of the Solar System, Mercury turns out to be 0.4 AU from the Sun, while Pluto is about 40 AU.

The Solar System remains the limit to our exploration of the Universe with spacecraft; our probes have penetrated only slightly beyond Pluto. But telescopes extend our view far beyond the Solar System to reveal that just as the Earth is but one of many planets orbiting the Sun, so too the Sun is but one of a vast swarm of stars orbiting the center of our galaxy, the Milky Way.

P.8 THE MILKY WAY GALAXY

The **Milky Way galaxy** is a cloud of several hundred billion stars with a flattened shape like the Solar System (fig. P.6). The Sun and other stars orbit the Milky Way at some 140 miles per second (220 kilometers per second), but so vast is our galaxy that it still takes the Sun about 240 million years to complete one trip around this immense disk. The Milky Way's myriads of stars come in many varieties, some hundreds of times larger than the Sun, others hundreds of times smaller. Some stars are much hotter than the Sun and shine a dazzling blue-white, while others are cooler and glow a deep red. Still others emit no light at all because their intense gravity prevents any light from escaping.

In the Milky Way, as in many other galaxies, stars intermingle with immense clouds of gas and dust. These mark the sites of stellar birth and death. Within cold, dark clouds, gravity may draw the gas into dense clumps that eventually turn into new stars, lighting the gas and dust around them. Stars eventually burn themselves out and explode, spraying matter outward to mix with the surrounding clouds. This matter from exploded stars is ultimately recycled into new stars (fig. P.7).

In this huge swarm of stars and clouds, the Solar System is all but lost—a single grain of sand on a vast beach—forcing us again to grapple with the problem of scale. Stars are almost unimaginably remote: even the nearest one to the Sun is over 25 trillion miles away. Such distances are so immense that analogy is often the only way to grasp them. For example, if we think of the Sun as a pinhead, the nearest star would be

*Because the Earth's orbit is actually an ellipse, the AU is technically defined slightly differently, a point we will discuss further when we consider planetary orbits.

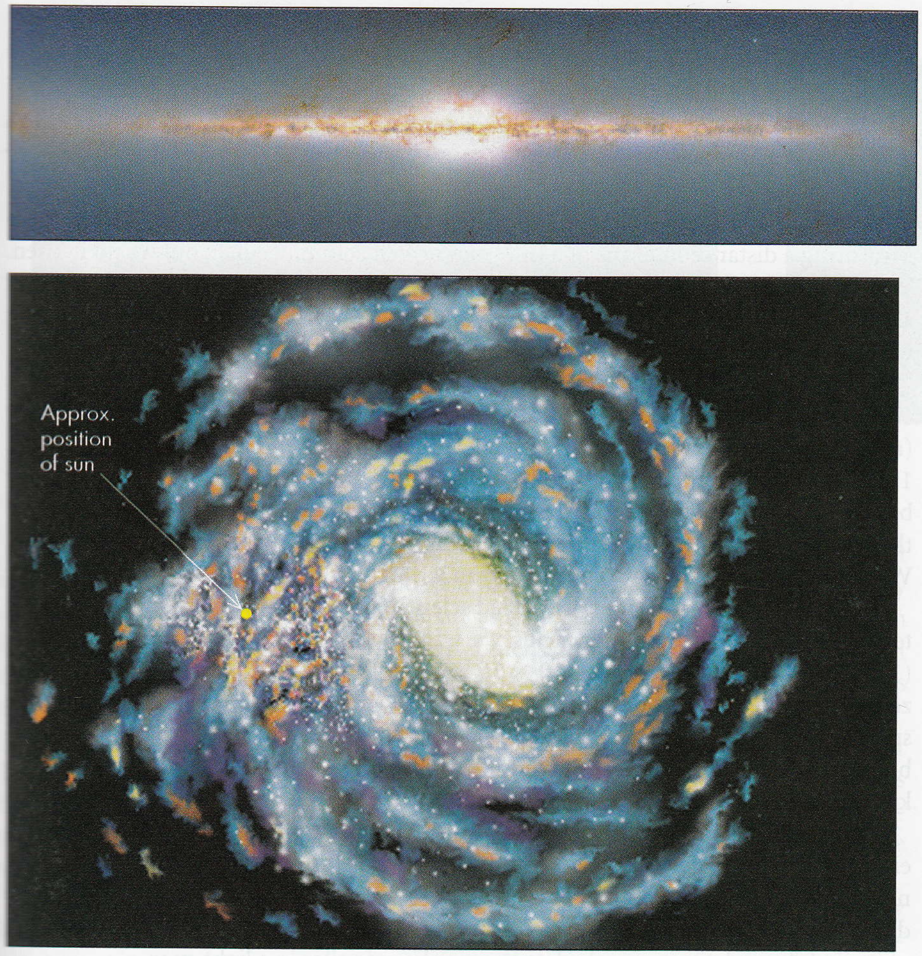


FIGURE P.6

The Milky Way galaxy. Top picture is a side view made by plotting stars in the 2MASS star catalog. Bottom picture is an artist's depiction of how our galaxy might look to an observer seeing it from above.

(Atlas Image courtesy of 2MASS/UMass/IPAC-Caltech/NASA/NSF.)

FIGURE P.7

Photographs of interstellar clouds in the Milky Way taken with an Earthbound telescope. On the scale of these pictures, the Solar System out to Pluto is about 1000 times smaller than the period ending this sentence. (A) A cold, dark cloud and a star cluster beside it. Dust in the cloud blocks our view of the stars behind it.

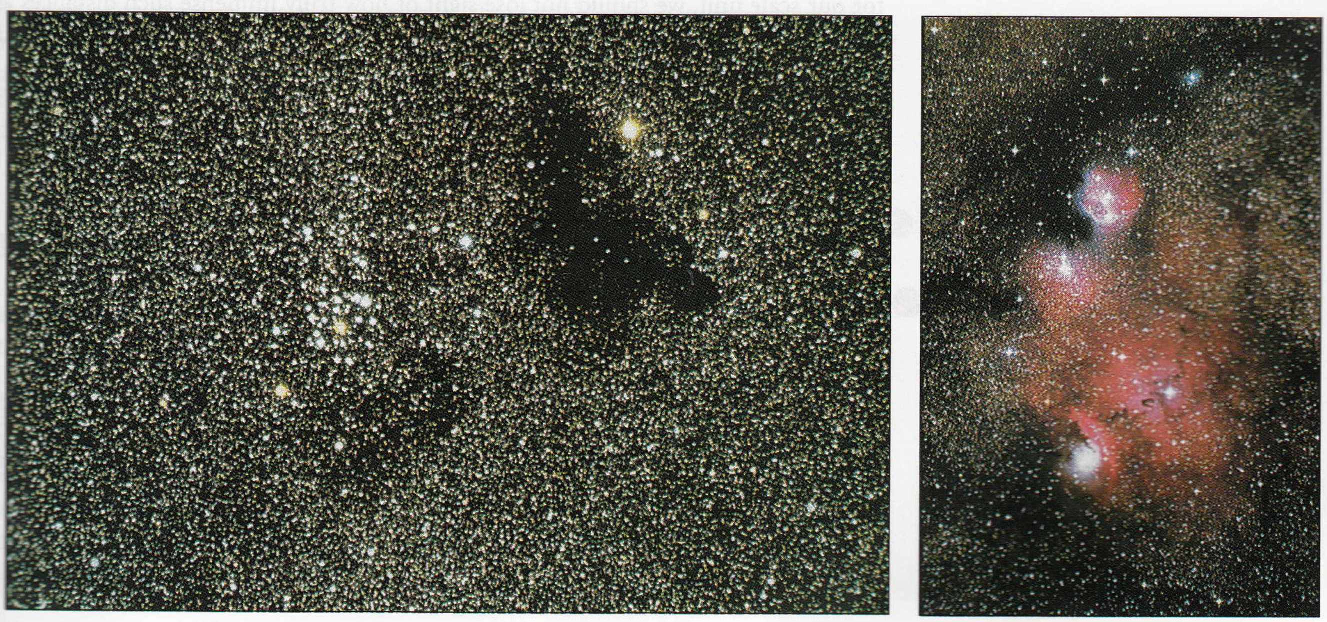
(Courtesy of David Malin, Anglo-Australian Telescope Board.)

(B) A group of clouds heated by young stars. Glowing hydrogen in the clouds creates their red color.

(Courtesy of Anglo-Australian Telescope Board.)

A

B



another pinhead about 35 miles away and the space between them would be nearly empty. In fact, distances between stars are so immense that even astronomical units are inappropriately small and so we again choose a new unit of length—the light-year.

P.9 THE LIGHT-YEAR

Measuring a distance in terms of a time may at first sound peculiar, but we do it often. We may say, for example, that our town is a 2-hour drive from the city, or our dorm is a 5-minute walk from the library, but expressing a distance in this fashion implies that we have a standard speed.

Astronomers are fortunate to have a superb speed standard: the speed of light in empty space, which is a constant of nature and equal to 299,792,458 meters per second (about 186,000 miles per second). Moving at this constant and universal speed, light in 1 year travels a distance defined to be 1 **light-year,** abbreviated as ly. As we will show below, this works out to be about 6 trillion miles (10 trillion kilometers). To demonstrate that, however, is cumbersome because it involves multiplying a series of large numbers. We therefore will use a more concise way to write them called powers-of-ten notation.

In **powers-of-ten notation** (also called **scientific notation**), we write numbers using ten to an exponent, or power. Thus we write $100 = 10 \times 10 = 10^2$ and 1 million (1,000,000) as $10 \times 10 \times 10 \times 10 \times 10 \times 10 = 10^6$. Instead of writing out all the zeros, therefore, we use the exponent to tell us the number of zeros. A number like the speed of light (186,000 miles per second) may also be written in powers-of-ten notation, becoming 1.86×10^5 miles per second. Likewise, the astronomical unit (150 million kilometers) can be written as 1.5×10^8 km.

One reason to use powers-of-ten notation is that multiplying and dividing becomes enormously easier. For example, to multiply two powers of ten we just add the exponents, and to divide we subtract them. Thus $10^2 \times 10^5 = 10^7$, and $10^8/10^3 = 10^5$. More details on using powers-of-ten notation are given in the appendix, but as an illustration of its usefulness, let us now calculate the number of miles in a light-year.

To find how far light travels in a year, we multiply its speed by the travel time. One year is about 31,600,000 (about 3.16×10^7) seconds.* Multiplying this by the speed of light we get 3.16×10^7 seconds $\times$ 1.86×10^5 miles/second $= 3.16 \times 1.86 \times 10^{12}$ seconds $\times$ miles/second $= 5.88 \times 10^{12}$ miles, or about 6 trillion miles (10^{13} kilometers), as we previously claimed. In these units, the star nearest the Sun is 4.2 light-years away. Although we achieve a major convenience in adopting such a huge distance for our scale unit, we should not lose sight of how truly immense such distances are. For example, if we were to count off the miles in a light-year, one every second, it would take us about 185,000 years!

We can now use the light-year for setting the scale of the Milky Way galaxy. In light-years, our galaxy is about 100,000 light-years across, with the Sun orbiting roughly 30,000 light-years from the center. Within the Milky Way's disk, stars are separated by a few light-years. The diffuse gas clouds scattered across its disk can be hundreds of light-years across.

P.10 GALAXY CLUSTERS AND THE UNIVERSE

Having gained some sense of scale for the Solar System and the Milky Way, we now resume our exploration of the cosmic landscape, pushing out to the realm of other galaxies. Here we find that just as stars are grouped into galaxies, so galaxies are themselves grouped into **galaxy clusters.**

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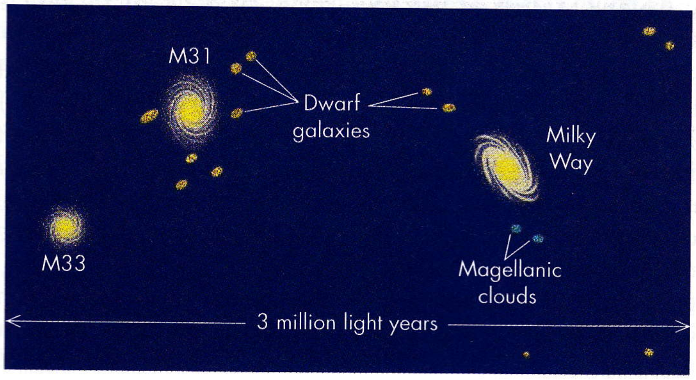
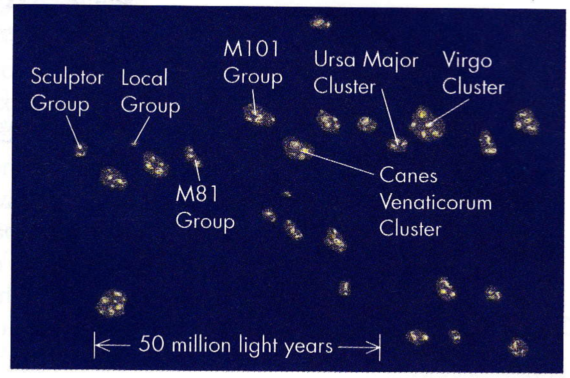
*Numbers here and elsewhere are rounded off.

A




B

FIGURE P.8

(A) The Milky Way, which is at right in the Local Group of galaxies and (B) the Local Supercluster. The patches are individual galaxy clusters. Our knowledge of these structures is still very incomplete, so this is an artist's interpretation of data gathered to date.

The cluster of galaxies to which the Milky Way belongs is called the **Local Group.** It is "local," of course, because it is the one we inhabit. The Local Group is small as galaxy clusters go, containing only about 30 galaxies as members, but it is still about 3 million light-years in diameter. Yet despite such vast dimensions, the Local Group is itself part of a still larger assemblage of galaxies known as the **Local Supercluster.** Figure P.8 puts this in perspective for us.

Our supercluster consists of a few dozen member galaxy clusters, spreading over 100 million light-years, but it is perhaps itself part of an even larger structure known as the Great Attractor, a cluster of superclusters, possibly as much as 200 million light-years across. Structures of such vast size are about the largest objects we can see before we take the final jump in scale to the **Universe** itself.

The visible Universe is the largest astronomical structure of which we have any knowledge. What we can know of it is limited to what we can observe using sophisticated Earth-based and space-based telescopes and instruments. Even its size and shape are only roughly known. For example, according to some theories the Universe extends limitlessly, while according to others it spans perhaps 15 billion light-years, gradually and imperceptibly curving back on itself to form a closed system much like the surface of the Earth. But regardless of our uncertainty about the known Universe's shape and size, we can observe that its structure is surprisingly well ordered. Small objects are clustered into larger systems, which are themselves clustered: planets around stars, stars in galaxies, galaxies in clusters, clusters in superclusters, and superclusters into even larger groups. Although astronomers do not yet understand completely how this orderly structure originated, they do know that gravity plays a crucial role.

P.11 GRAVITY

Gravity gives the Universe structure because it creates an attraction between *all* objects. You can see that attraction even in everyday life. For example, if you drop a book, the Earth's gravitational force makes the book fall. Moreover, that same force spans the vast distance between the Earth and the Moon to hold our satellite in its orbit. Similarly, gravity holds our planet in its orbit around the Sun and the Sun in its orbit around the Milky Way.

Although gravity dominates the large-scale structure of the Universe, other forces dominate on smaller scales. To understand these forces, we need to look briefly at the small-scale structure of matter.